CALCULATION OF DENSITY OF DEFECTS FROM GAMMA IRRADIATION

by

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A method for calculating the density of defects to be expected from Compton electrons formed by incident γ-irradiation of a given material is described. The calculation involves experimental knowledge of the rate of introduction of defects, $dN_d/d\phi$, where N_d is the density of defects and ϕ the integrated electron flux, the range-energy curve for electrons, and the theoretical spectrum of Compton electrons given by the Klein-Nishina formula. A specific calculation has been made for the density of defects at the band energy level 0.17 eV below the conduction band energy, E_c, in n-type silicon irradiated by 1.37 MeV Co^{60} γ-rays. Sonder and Templeton[1] found a defect production rate of 1.35×10^{-3} defects per cm path of Co^{60} photons in 2 Ohm-cm silicon containing oxygen. Using this production rate, they calculated the defect production rate per Compton electron, which turned out to be by a factor of ten smaller than the experimental production rate for accelerator electrons of comparable energies. The result of the present calculation is in reasonable agreement with their experimental data of 1.35×10^{-3} cm^{-1}. It corrects their theoretical calculation by determining the

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equilibrium spectrum of the Compton electron flux, N(E), which results from the degradation of electron energy in ionizing collisions.

The first step is to calculate the original Compton spectrum[2] as cut-off by the maximum electron energy, which is proportional to $d\Phi_c/d\epsilon$ where Φ_c is the Compton cross section per target electron which acquires an initial energy ϵ. This spectrum is shown in Figure 1.

It is then possible to calculate the number of equilibrium electrons, N(E), with energy between E and E + dE crossing a unit area within an infinite medium by summing over all electrons which will have the energy E at the plane located at $z = 0$. For a unit fluence of gammas in the z-direction,

$$N(E)dE = \int_E^{E_{max}} d\epsilon \int_0^{\infty} dz \int_0^{\pi/2} \sin\theta d\theta \int_0^{2\pi} d\phi N_e \frac{d\Phi_c}{d\epsilon} P(z, \theta, \epsilon, E)\, dE \qquad (1)$$

where ϕ is the azimuthal angle for the z-direction, N_e is the number of electrons/ cm^3 and $P(z, \theta, \epsilon, E)$ dE is the probability that an electron of energy ϵ which has been scattered at an angle θ with respect to the incident direction of the gamma ray at a distance z away from the flux plane will have an energy between E and E + dE. $P(z, \theta, \epsilon, E)$ will on the average be unaffected by elastic scattering of the electrons by nuclei since as many electrons are scattered away from as toward a given polar direction θ. The expression for P, normalized over all energies, is

$$P(z, \theta, \epsilon, E)\, dE = \frac{dR}{dE} \left| E^1 \, \delta \left| R(\epsilon) - R(E) - z/\cos\theta \right| dE \qquad (2)$$

[redacted]

where δ is the Dirac delta function, R is the range, and E' is given by: $R(E') = R(\epsilon) - z/\cos\theta$. The expression for $d\Phi_c/d\epsilon(\epsilon, \theta, \phi)$, normalized over all angles, is:

$$d\Phi_c/d\epsilon\ (\epsilon, \theta, \phi) = \frac{d\Phi_c/d\epsilon\, \delta\left(\theta - \theta_\epsilon\right)}{2\pi \sin \theta_\epsilon} \tag{3}$$

where θ_ϵ is the angle of scattering corresponding to ϵ. The indicated integration gives:

$$N(E)dE = dE\ N_e \frac{dR}{dE}\Big|_E \int_E^{E_{max}} d\epsilon \frac{d\Phi_c}{d\epsilon} \cos \theta_\epsilon\ . \tag{4}$$

The final integration was performed numerically and the range-energy relation for silicon was assumed equal to the expression for aluminum when the density, ρ, for silicon was used. Thus, from Marton[2],

$$R(cm) = (0.412/\rho)E^{(1.265-0.0954 \ln E)}$$

when E is given in MeV and ρ in gm/cm^3. The equilibrium spectrum is also given in Figure 1.

A graph of $dN/d\phi$ versus E is shown in Figure 2 for the defect located at E_c - 0.17 eV. The curve represents the average of the latest data by Carter and Downing[3], which appears to be the most extensive and consistent data available. The data by Flicker, Loferski, and Scott-Monck[4], representing relative values only is normalized to the Carter and Downing data at 800 KeV. It is realized that the curve may have a spread of a factor of two if only because of variations in $dN/d\phi$ which occur for samples of different resistivities.

The final calculation for N_d is given by

$$N_d = \int_0^{E_{max}} dE\, N(E) \cdot (dN_d/d\phi) \tag{5}$$

or $N_d = 2.2 \times 10^{-3}/cm^3$ per unit integrated flux of γ's. This number is a factor of two larger than the experimental data of Sonder and Templeton[1]. However, the latter authors have estimated that their value should be low by 30-50% due to the geometry of the counting device.

REFERENCES

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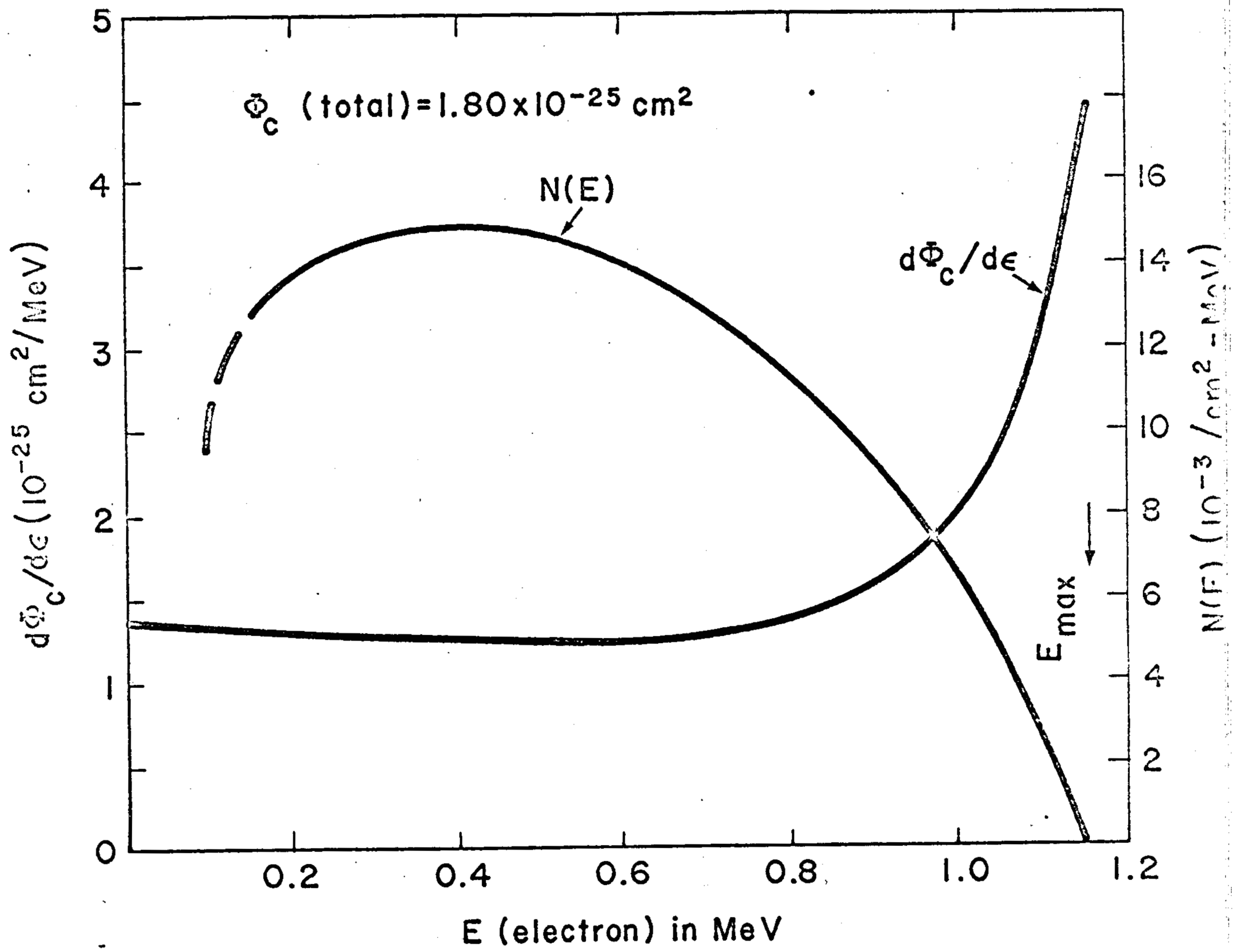

Figure 1 – Compton Electron Spectrum from Co^{60} γ-rays.

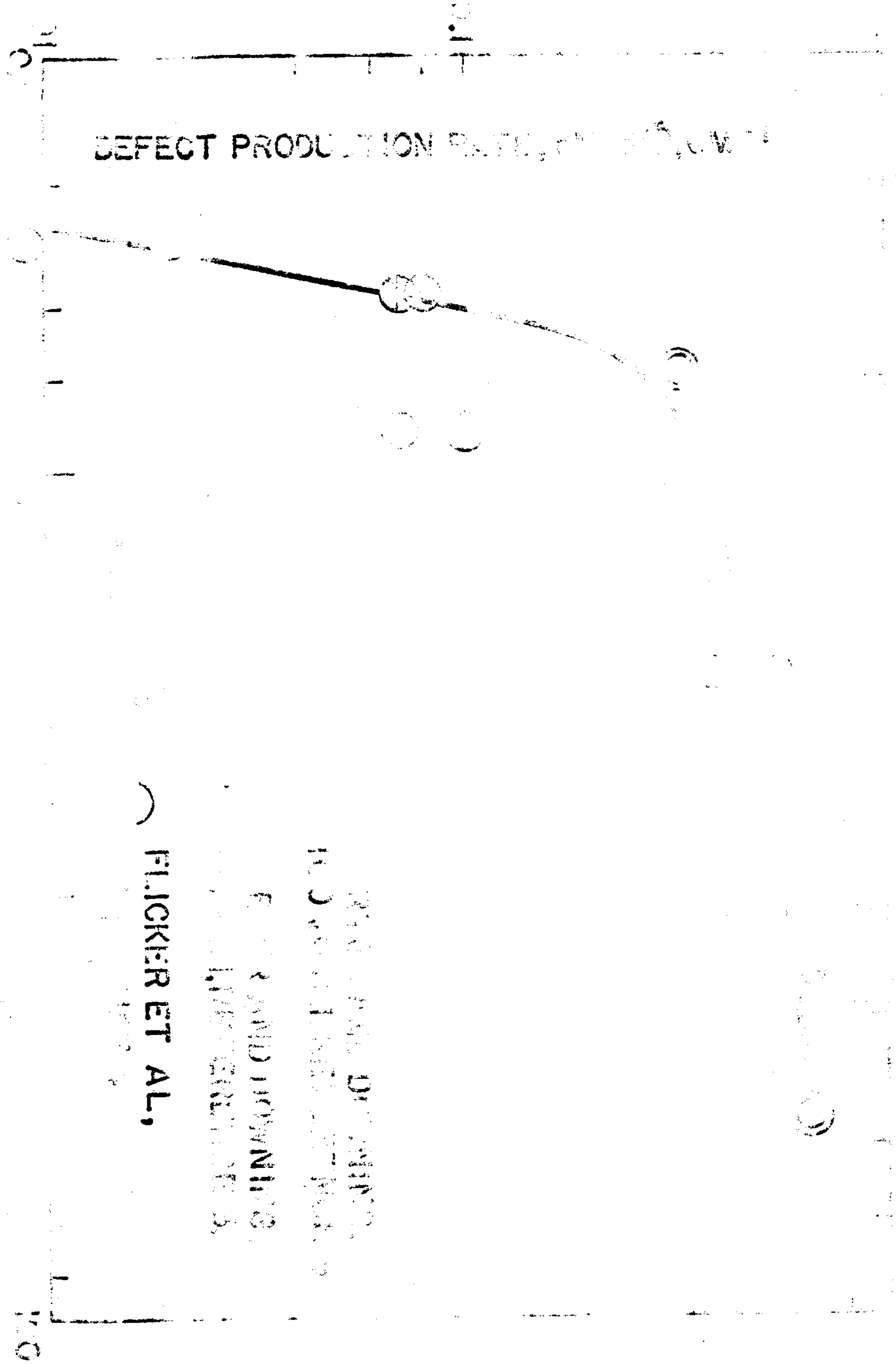

Figure 2—De